# Science Meets Traditional Knowledge: Water and Climate in the Sahtu (Great Bear Lake) Region, Northwest Territories, Canada

Ming-ko Woo[1,2], Paul Modeste[3], Lawrence Martz[4], Joe Blondin[3], Bob Kochtubajda[5], Dolphus Tutcho[3], John Gyakum[6], Alphonse Takazo[3], Chris Spence[7], Johnny Tutcho[3], Peter di Cenzo[8], George Kenny[3], John Stone[9], Israel Neyelle[3], George Baptiste[3], Morris Modeste[3], Bruce Kenny[3], Walter Modeste[3]

ABSTRACT

In July 2005, several scientists from the Mackenzie GEWEX (Global Energy and Water Cycle Experiment) Study or MAGS, met with aboriginal people in Deline on the shore of Great Bear Lake to exchange information on climate and water in the region. Topics discussed pertained directly to the northern environment and they included climate variability and change, wind, lightning, lake ice, lake level and streamflow. Traditional knowledge shared by the residents is a rich source of local expertise about the landscape and climate systems of the Deline area while the scientific knowledge provided by MAGS presents a scientific basis for many observed climate and water phenomena, particularly on a broad regional scale. Through cordial and open discussions, the meeting facilitated the sharing of traditional knowledge and scientific results. The meeting enhanced the potential for traditional knowledge to help direct and validate scientific investigations and for scientific knowledge to be used in conjunction with traditional knowledge to guide community decision-making.

Key words: Weather and climate, water resources, atmospheric science, hydrology, traditional knowledge, northern environment, Deline, Great Bear Lake

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[1] Corresponding author: woo@mcmaster.ca

[2] Program Leader, MAGS; Professor, School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario L8S 4K1, Canada

[3] Deline Renewable Resources Council, P.O. Box 156, Deline, Northwest Territories X0E 0G0, Canada

[4] Professor, Department of Geography, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5A5, Canada

[5] Research Scientist, Hydrometeorological and Arctic Lab, Meteorological Service of Canada, Edmonton, Alberta T6B 2X3, Canada

[6] Professor, Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, Quebec H3A 2K6, Canada

[7] Research Scientist, National Water Research Institute, Environment Canada, Saskatoon, Saskatchewan S7N 3H5, Canada

[8] Manager, MAGS Research Network, National Hydrology Research Centre, Saskatoon, Saskatchewan S7N 3H5, Canada

[9] Adjunct Research Professor, Department of Geography and Environmental Studies, Carleton University, Ottawa, Ontario K1S 5B6, Canada

# INTRODUCTION

Dené traditional knowledge is concerned with air, water, land, wildlife and people, and the ways in which they interact with one another. For millennia, people of the Mackenzie Basin have lived with, used, and learned about snow, ice, frost, lakes, and rivers in a cold climate (Deline First Nation, 2005). Water and climate are also the foci of scientific investigation by the researchers of the Mackenzie GEWEX (Global Energy and Water Cycle Experiment) Study or MAGS, a collaborative research network that conducted studies of the air and water in the Mackenzie Basin from 1994-2005 (Rouse et al., 2003a). In July 2005, a meeting was held between a delegation of MAGS scientists and the community of Deline, NT, Canada. The purpose of the meeting was to exchange information with the aim of gaining a better understanding of the atmospheric and water environments through a sharing of traditional and scientific knowledge.

The Natural Sciences and Engineering Research Council (NSERC) of Canada programs under which the MAGS Network was partially funded, expected the scientific team to communicate with communities and stakeholders in the research area. Initial communications with the Deline community (discussed in following section) resulted in an invitation for more interactive discussion of the scientific findings of the MAGS study and the implications of these for the community. Community leaders also expressed a keen interest in exploring approaches to the environment that differ from those of Traditional Knowledge and in becoming more familiar with scientists and with scientific perspectives and research methods. The scientific team was motivated by the excitement of sharing the results of their study, the opportunity to learn from the experience of residents and the potential of using local knowledge to validate their findings.

Scientific knowledge and traditional knowledge are based on different world views, use different methods for acquiring and disseminating knowledge and usually focus on different spatial scales (Table 1). Traditional knowledge is based on generations of keen observations and experiential understanding of the natural environment in the territory over which hunting, trapping, fishing, and social activities are carried out. MAGS science is regional in scope, covering a 1.8 million $km^2$ territory, examining its atmospheric and hydrologic conditions over a 12-year time span (1993-2005), but also using data from historical archives that can extend back over half a century. Information from local levels is invaluable to the validation of regional results. Also, a regional knowledge of the fluxes of heat and air and the flow of water offers a broad picture that enhances understanding of the local patterns of wind, ice, snow and stream discharge. Traditional knowledge is integrative, considering the environment as a whole entity that provides physical as well as spiritual well-being to the people (Mackenzie Valley Environmental Impact Review Board, 2005). Western science, on the other hand, tends to take a reductionist approach, making in-depth examination of specific elements of the environment.

Riedlinger and Berkes (2001) suggest that traditional knowledge can complement scientific knowledge by "...the use of traditional knowledge as local scale expertise; as a source of climate history and baseline data; in formulating research questions and hypotheses; as insight into impacts and adaptation in Arctic communities; and for long term, community-based monitoring" (p. 315). The objectives of the MAGS Deline meeting were to explore these potential uses of traditional knowledge to enhance scientific understanding of the integrated climate and water system of the Mackenzie River Basin and to discuss the potential for this scientific understanding to complement aboriginal community knowledge systems at the local level.

MAGS can claim no special expertise in subjects other than the atmospheric and hydrologic sciences. Nevertheless, a meeting of MAGS scientists with the aboriginal people of Deline provided an invaluable opportunity for the direct exchange of information on climate and water between holders of traditional and scientific knowledge about a common area. The authorship of this paper reflects the collaboration of MAGS scientists and Deline community representatives in its preparation. It reports the dialogue between a community endowed with first hand knowledge of the northern environment through its cultural heritage and livelihood, and a group of scientists with considerable expertise on the climate and hydrology of cold regions.

## BACKGROUND

Deline is located in the Northwest Territories of Canada at 65°N 123°W (Fig. 1) at the western end of Keith Arm (North Slavey name is Dahreli) of Great Bear Lake (Sahtu), close to where the Great Bear River (Sahtu De) flows from the lake. Deline was officially known as Fort Franklin until 1993 when the Sahtu Dené and Métis Comprehensive Land Claim Agreement was signed. That year the people of Deline reclaimed their own name for the community, which means "where the water flows" in the North Slavey language (a reference to the headwaters of the Great Bear River). Today it is a community of approximately 700 people of whom 93% are Dené and Métis of Slavey heritage. The community is situated in a sheltered bay near the mouth of the

Great Bear River and was a traditional gathering place for people of the region long before the village was established.

There was considerable interaction between MAGS and the Deline community prior to the meeting of July 7-8, 2005. In 2003, the community was engaged to assist in snow and lake-ice investigations on Great Bear Lake. Six people from Deline were trained and hired to assist in setting up of field sites and making field observations. This capacity building initiative was very successful and was extended through 2005 and 2006. MAGS representatives visited the community on three occasions (May 2004, October 2004 and February 2005) to share knowledge through formal and informal presentations to various community groups including the elders, community leaders, members of the Deline Renewable Resources Council (DRRC), the schools and the general public. In addition, members of the DRRC attended and presented talks at Scientist-Stakeholder Meetings sponsored by MAGS.

The rapport established through these interactions generated interest in the community to hear more about MAGS research and resulted in a formal invitation for MAGS scientists to participate in a larger community meeting focussed on two-way information sharing. The meeting, held on July 7-8, 2005, was attended by seven MAGS scientists and 15 Deline participants selected by DRRC. The DRRC-selected participants provided a good cross-section of the community and included elders, DRRC members, people from the community who live and work on the land, and high school students. A local interpreter facilitated translations between English and North Slavey.

The meeting was designed to encourage interactive sharing of information and ideas. It was structured around a series of informal presentations by scientists and community representatives on topics that encompassed climate variability and change, wind, lightning, lake ice, lake level and streamflow. These were interspersed with open-ended breakout sessions of scientists and community members. Discussions were not taped at the request of the community participants, but hand-written notes were taken during the meeting. Quotations from community representatives (presented in italics in this article) were authenticated at the meeting and through manuscript review by our Deline co-authors.

The meeting began with a traditional prayer by a community elder and a general discussion of traditional and scientific knowledge systems followed. MAGS scientists provided an overview of scientific inquiry and Deline community elders outlined the nature and scope of traditional knowledge. Dené traditional knowledge was described as encompassing air, water, land, wildlife and people, and the ways in which they interact with one another; and as having an essential ethical and spiritual dimension that guides the way in which people interact with one another and with their environment. The significance of the differences between traditional and scientific understanding of the world were discussed. Several community participants observed that traditional knowledge systems are not static but are continuously evolving through the incorporation of new information from a variety of sources which can include scientific research.

## TOPICS ON CLIMATE AND WATER

## Climate Warming and Variability

The Mackenzie Basin is an area that has experienced the largest warming in Canada during the last 50 years and Deline is situated at the centre of a zone where mean annual temperature has risen by over 1.5°C since 1950 (Fig. 2). Instrumental records from Norman Wells and Fort Simpson (Fig. 1), the nearest stations with long-term records, further indicate that most of the warming occurred in the winter. If only the months of November to April are considered, both Norman Wells and Fort Simpson data showed an average temperature rise of 0.06°C/year (Fig. 3). Summer temperatures, however, show no apparent trend. The reported recent trend of global warming (ACIA, 2005) refers to average condition for the entire globe, with considerable regional deviations from this general trend (Zhang et al., 2000). For example, from a regional perspective, warming in western Arctic was paralleled by cooling of the eastern Arctic (Fig. 2).

*"What was it like before 1950?"* was a question raised at the meeting.

Fort Simpson has an air temperature record that goes back to the beginning of the 20th Century. It can be seen from this instrument record (Fig. 4) that there were years in the 1940s with warm conditions comparable to those of recent decades. This is not surprising since the Earth's climate is driven by natural as well as by human forces. For instance, changes in radiation emission from the Sun, or major volcanic eruptions that disgorge water vapour and gases into the atmosphere, can all induce regional or global variations in climate. On the other hand, human activities that produce an increasing amount of greenhouse gases, including carbon dioxide and methane, since the industrial revolution, also are a contributing factor that affects the Earth's climate (IPCC, 2001).

One notable climatic feature is the large year-to-year variation in temperature. Climate models and observations indicate that the Mackenzie Basin has the largest inter-annual temperature variability in the Northern Hemisphere (Kistler et al., 2001). Traditional Knowledge confirms that there are wide fluctuations in temperature. For example, 1998 was an exceptionally warm year and the subsequent year was cold again.

*"Ten years ago, we had intense cracking of the ice* (formation of contraction cracks due to coldness) *but not any more nowadays".* Community participants initially attributed this to climate change; more specifically, to winter warming. However, MAGS scientists noted that the complex relationship between ice cracking and air temperature can confound any direct linkage between the observed warming and ice cracking intensity. More information on the local scale (such as water temperature, ice thickness, snow cover, ice properties) is required to clarify the role of climate warming in reducing the formation of ice cracks.

Wind

The morning calm of July 7 was accompanied by numerous mosquitoes which, thankfully, were removed by the breeze that sprang up in mid-day. The incidence of afternoon breeze following a calm summer morning is well known in traditional knowledge. *"This breeze is present not more than 4-5 km inland".* This is evidence of the sea-breeze effect generated by the large lake. In summer, the land is heated up more than the water. The rising hot air from the land is countered by the subsidence of cool air over the lake, setting up a convection cycle that drives the cool air onshore to replace the rising air. This sea breeze mechanism occurs within short distance from the shore where land-water heating contrast is maintained, and is effective only after differential heating has created the local convection (Schertzer and Croley, 1999). During days when the regional air flow is strong, local temperature contrasts are suppressed and the sea breeze is replaced by the regional wind, as was experienced on July 8.

*"October is a windy period and we do not go out fishing in the lake".* The instrumental record from Norman Wells for the period 1970-2004 shows that wind speed tends to be lower in summer than winter as indicated in Fig. 5. Summer is generally a time with low winds, with wind speeds increasing in October and on into winter (although wind speeds continue to increase into winter, it is the October increase that is most noticeable by the locals as the lake is still ice free and boats can still be used). Increase in fall wind speeds can be attributed to the southward advance of the cold continental Arctic air mass and increased frontal cyclonic activity (Burns, 1973). There has been a tendency for winter winds to diminish in recent years, especially for the high winds which now attain lower magnitudes than in the 1970s. This warrants further investigation but is beyond the scope of the present paper.

Precipitation

*"There was much snow last winter (2004-05). Only the backside of caribou was seen above the snow".* Significant winter precipitation is often associated with the 'pineapple express' (Lackmann et al. 1998; Lackmann and Gyakum 1999), which is warm, moist subtropical air that flows northeastward from near the Hawaiian Islands to the West Coast and across the Cordillera,

to reach the Mackenzie Basin (Fig. 6). This flow of subtropical air may produce large amounts of precipitation in the Basin.

*"Snow accumulation was not through heavy storms, but from many events".* Satellite imagery (NOAH – AVHRR) reveals the existence of a band of large snow water equivalent over 100 mm (snow water equivalent is the amount of water obtained by melting a sample column and measuring its depth). This band recurs every winter and is aligned with the northern fringe of the boreal forest (Derksen and MacKay, 2006). Simulations using the Canadian Regional Climate Model suggest that frequent frontal activity in the late autumn and early winter is responsible for the snowfall events, depositing much snow on the northern boreal forest. Deline is located within this zone.

*"There was deep snow in the bush, but not on the muskeg". "We had rain last December. It froze with the snow. The caribou could not dig down to find food and moved to the southwest".* Snow drifting is common in open environments and, therefore, the wetlands (or muskeg) would have less snow accumulation than the woodlands. Such a pattern of snow distribution is naturally of importance to winter over-snow travel and to wildlife. Mid-winter rain or snowmelt can deny wildlife access to its feed because rainwater and meltwater that percolate through the snow can freeze at the cold ground surface to form ice. The presence of ground-fast ice in the snow often becomes an effective barrier to foraging as it is hard for the caribou to dig through (Miller et al., 1982).

Lightning, Thunder and Fire

Lightning and thunder from cumulonimbus clouds are among the most spectacular natural phenomena on earth. The lightning mechanism within these thunderstorms is likened to shuffling one's feet across the carpet to acquire excess electrical charge which is discharged by a spark when one touches another body. There are two key types of lightning discharges: flashes between the cloud and the earth (cloud-to-ground discharges) and flashes within the cloud (intra-cloud discharges). Discharges can also occur from the cloud to the sky or between clouds but they are less frequent (Uman, 2001).

Lightning activity typically starts the majority of fires in the boreal forests of the Mackenzie Basin (Kochtubajda et al., 2002). Elders have observed that "*There was much lightning but less fire in the past.*" Although fires are beneficial to the control of forest diseases and insects as well as maintaining biological diversity, the consequence of fire impacts the traditional land-based lifestyle by destroying habitat that is used for hunting, trapping and harvesting berries and herbal medicines.

The sound of thunder produced by the lightning flashes around Great Bear Lake in the past "*used to be louder and stronger*". A rough rule-of-thumb to estimate the distance of the lightning source in kilometers is to count the seconds between the flash and the bang, and divide by 3 (Few, 1975). Generally, thunder cannot be heard much more than 25 km from its source (Bhartendu, 1969), though several factors including temperature gradients and wind shear in the atmosphere can influence the range of audibility.

*"In the last 30 years, there are more fires and now the lightning is not so strong but there are more strikes"*. The decadal changes in the number of large forest fires and areas burned within 100 km of the Deline community, obtained from the Large Fire Database (Stocks et al., 2002), are shown in Table 2. These data confirm the local observations. There were 39 large fires (>200ha) that burned nearly 350,000 hectares between 1971 and 1998. During the 1971-80 decade, four large fires consumed approximately 12,000 hectares, but those numbers dramatically increased to 19 large fires and approximately 236,000 hectares during the 1991-98 period. Does this suggest an increasing trend in lightning? Most forest fires in this region are lightning-initiated, but these disturbances also depend on such critical elements as available fuel (including dry leaves, twigs and branches) and weather. Weather affects the ignition of fires through lightning, but it also influences the fire behaviour. Strong winds, high temperatures, low humidity, and precipitation for example, influence the rate of fire growth.

Lightning sensors set up by the NWT lightning detection network, for the summer season of June to September for the period 1994 to 2002 provided data to examine several lightning characteristics within a 25 km radius of Deline (Table 3). Several observations can be made. Typically, an annual average of about 72 cloud-to-ground strikes has been detected on 10 days within the Deline area but this activity can vary greatly from one year to the next. Nearly half of the seasonal lightning in the area usually can be attributed to the storms from one day. Lightning strikes within 5 km of the community are rare. The majority of lightning during the study period occurred beyond 10 km; the average distance being about 19 km away from the community which is near the limit where thunder is still audible.

Lake Ice

The process of ice formation on large lakes is generally well understood by western science. Once the water cools to below freezing, shore or border ice forms first as it is relatively protected from high winds that could disturb the freezing process (Gerard, 1990). Traditional knowledge describes how these processes are manifested on Great Bear Lake. *"The Arms of Great Bear Lake freeze first, and middle of the lake does not freeze up until December"*. *"In the last winter (2004-05), November was calm and ice was able to form quickly across Great Bear Lake. Previously, the winds were strong and they drove the ice around, pushing it to the shore and piling up ice ridges with slush; but the last time we saw such ridges was in 1984"*. Satellite imagery (AMSR – 89 GHz images) clearly indicates rapid freeze up of the lake between November 7 and 17 in 2004. The map in Fig. 7 for 18:00 MDT on November 10, 2004, illustrates the meteorological conditions typical for this 10-day period of freeze-up. At this time, Great Bear Lake was situated in a region of very weak winds (less than 5 knots) and under a strong ridge of high pressure with anomalously cold air. This extended period of cold, nearly calm conditions permitted the development of an extensive ice cover across the lake without blowing the initially formed ice towards sheltered embayments.

Furthermore, as the winter progresses the relationship between snow depth and ice thickness becomes apparent. *"More snow is warmer climate; ice thickness is less. Less snow is colder climate; ice thickness is greater"*. Two sets of lake ice thickness made through ice-auger holes and snow depth measurements made in Keith Arm of Great Bear Lake in late March show that the ice reached 137 and 88.5 cm thickness in March 2004 and March 2005; and the snow depth at these times were 17 and 26 cm, respectively. Insulating properties of snow affect the chilling of lake water, hence the deeper the snow, the thinner the lake ice (Gerard, 1990; Duguay et al., 2003). Local observations by Deline elders point to a decrease of ice thickness from 8 feet (2.4 m) in the past to about 6 feet (1.8 m) in recent winters. This may suggest warmer winters (Fig. 3) but can be indicative of more snow accumulation. For example, Zhang et al. (2000) found an increase in snowfall amounts north of 55°N.

There is a societal advantage to utilize traditional knowledge about the lake ice of Great Bear for winter travel. *"In a fog on the lake ice, traditional knowledge tells you not to follow the snow drifts but to drive across them. Some young men did not heed this and drove their skidoos along the snow drifts, only to plunge into open water at the outlet of the lake".* The traditional knowledge of ice processes is an important consideration in travelling and fishing. Normally, open water conditions may persist near the mouth of the lake. Elders noted that the predominant winds at Deline over winter are from the east and these would create snowdrifts that point to the lake outlet.

*"The ice usually goes out in Keith Arm in late June/early July, and it was unusual that the ice stayed until late-July in 2004".* During the two seasons when MAGS conducted a field study of Great Bear Lake, ice breakup was late in 2004 (July 27) but was early in 2005 (June 14). Duguay et al. (2006) have examined freeze-up and break-up dates for selected lakes in the Mackenzie Basin, but could not find any statistically significant trends. It is likely that any trend, if present, was masked by large interannual variability as exemplified by the 2004 and 2005 break-up events.

Several factors influence the ice melt rate and duration. Ice thickness is an obvious consideration (Ashton, 1983). While clear ice permits greater penetration of radiation to effect internal melt (Gerard, 1990), dirty ice has lower albedo to enhance surface ablation. Shore ice melt is accelerated by runoff from the land and a floating ice cover is prone to attrition as the ice floes are driven by the wind to crash against each other or crush against the shore (Heron and Woo, 1994). It may be that the ice thickness, weather and runoff inputs offered favourable conditions for a late break up in 2004.

Lake Level and Streamflow

For many generations the people living in the region have relied on Great Bear Lake both as a source of food "*the lake is our supermarket*" and for transportation both in summer by boat and over the ice in winter. *"The lake goes up and down every year. We do not notice much change in its level over the years"*. It is normal for lake levels to fluctuate annually and seasonally in response to precipitation and temperature, and over shorter periods due to storm surges and wind build-up when strong winds blow along long fetches (Schertzer and Croley, 1999). There is a pronounced seasonal rhythm in the fluctuation of Great Bear Lake, with minimum water levels occurring in April at the end of the cold season and before spring melt occurs (Fig. 8). Snowmelt and precipitation during the spring and summer contribute to raising levels which peak in August or September. Decreasing input of water into the lake during fall and winter, accompanied by continuous lake discharge into the Great Bear River, produces a steady decline in lake level to reach its annual minimum at the end of winter.

Precipitation and temperature are predominantly responsible for interannual variability in lake level (Schertzer and Croley, 1999). A year with increased precipitation and lower temperature results in wet conditions that raise the lake level, so that a sequence of wet years will produce a rising trend. Conversely, a series of dry years causes the lake level to drop from year to year. When a sequence of wetter years alternates with a sequence of dryer years, a cyclic pattern of annual lake level results, like that exhibited by Great Bear Lake (Fig. 8). These long-term tendencies are often masked by the within-year variability (0.2-0.4 m) such that the multi-year trend can be detected only through the instrumental records of the lake level.

Comparing the average lake level for a relatively low 3-year period (1988-1990) with that for a relatively high 3-year period (2001-2003) yields a difference of 0.16 m. Such a difference in water level translates into a large change in lake volume, considering that Great Bear is the seventh largest lake in the world with a surface area of over 31,500 $km^2$. A difference of 0.16 m is equivalent to a change in lake volume of 5.04 $km^3$. A continued trend of lake level drop(rise) can lead to a decline(increase) in lake outflow which, in turn, affects the discharge of Great Bear River.

The residents of Deline are most familiar with the flow regime of rivers in the area. *"Several years ago, engineers built a bridge across Porcupine River, a tributary of Great Bear River, without reference to traditional knowledge. The river crossing site was examined in the summer during low flow conditions and the bridge was erected at that crossing point. Came spring and the snowmelt runoff washed the bridge down the river, costing much money to bring it out".*

The Porcupine River follows a nival streamflow regime (Woo, 2000) in which snowmelt produces high flows that can be orders of magnitudes larger than the summer discharge. Future engineering designs can benefit from consultation with local residents whose traditional knowledge can provide insight not available from brief visits to the sites.

## CONCLUSION

This report documents a meeting of scientists and representatives of an Aboriginal community for the purpose of direct information exchange and communication. Traditional knowledge as a source of local scale expertise about the regional landscape and climate systems is especially valuable. The elders of the community have in-depth knowledge of the lake and land resources and the way these are linked to climatic phenomena. A number of interesting points raised in these discussions suggest research hypotheses that could be investigated jointly using scientific techniques and traditional knowledge.

A major goal of the meeting was to communicate the principal MAGS research findings of interest to the community, concerning climate and water resource phenomena. Scientific knowledge was not generally seen as supplanting traditional knowledge, but rather as a useful source of additional information that complements traditional empirical information and can be applied within a traditional moral and ethical framework. A view was expressed during the meeting that the community knowledge system continuously incorporates new information from scientific and other sources to build upon its traditional foundations. This underscores the importance of making research results accessible through appropriate publication and direct dialogue between scientific and traditional knowledge keepers.

Discussions about the physical environment proved to be an effective vehicle through which knowledge exchange was conducted. Both parties acknowledged an initial lack of familiarity of each other's knowledge base. The meeting demonstrated the value of direct dialogue in providing scientists with an appreciation of the richness and importance of traditional knowledge and in providing community members with an understanding of the scope, relevance and reliability of scientific studies. All participants were pleased with the cordial and open nature of the information exchange. There was a consensus that the Deline meeting had enhanced the potential for traditional knowledge to help direct and validate scientific investigations and for scientific knowledge to be used in conjunction with traditional knowledge to guide community decision-making. The outcome of this direct dialogue leads us to strongly recommend that such opportunities should continue to be pursued.

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Table 1: Comparison of traditional and scientific knowledge styles (Alaska Native Science Commission, 2005)

| **INDIGENOUS KNOWLEDGE** | **SCIENTIFIC KNOWLEDGE** |
|---|---|
| assumed to be the truth | assumed to be a best approximation |
| sacred and secular together | secular only |
| teaching through storytelling | didactic |
| learning by doing and experiencing | learning by formal education |
| oral or visual | written |
| integrated, based on a whole system | analytical, based on subsets of the whole |
| intuitive | model- or hypothesis-based |
| holistic | reductionist |
| subjective | objective |
| experiential | positivist |

Table 2: Three decades of fire activity within 100-km radius of Deline (data source: Government of the Northwest Territories).

| | Number of Fires | Area Burned (ha) |
|---|---|---|
| 1971 - 1980 | 4 | 11565 |
| 1981 - 1990 | 16 | 94095 |
| 1991 - 1998 | 19 | 235856 |

Table 3: Seasonal characteristics of lightning activity within a 25-km radius of Deline (data source: Canada Forest Service).

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 1994-2002 Average |
|---|---|---|---|---|---|---|---|---|---|---|
| Total strikes | 31 | 28 | 117 | 82 | 104 | 55 | 86 | 50 | 93 | 71.8 |
| Lightning days | 7 | 5 | 14 | 14 | 13 | 6 | 15 | 7 | 10 | 10.1 |
| Strikes within 1 km | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 0 | 0.44 |
| Strikes within 5 km | 1 | 1 | 3 | 7 | 4 | 0 | 8 | 1 | 7 | 3.6 |
| Strikes within 10 km | 3 | 6 | 17 | 22 | 20 | 2 | 13 | 11 | 19 | 12.6 |
| Percentage of strikes, 10-25 km | 90.3 | 78.6 | 85.5 | 73.2 | 80.8 | 96.4 | 84.9 | 78.0 | 79.6 | 83.0 |
| Average distance of lightning, 10-25 km | 20.0 | 19.6 | 18.6 | 18.4 | 17.9 | 18.7 | 19.6 | 18.4 | 17.4 | 18.7 |
| Maximum 1-day lightning strikes | 9 | 11 | 74 | 29 | 40 | 35 | 41 | 27 | 66 | 36.9 |
| 1-day strikes, percentage of seasonal total | 29.0 | 39.3 | 63.2 | 35.4 | 38.5 | 63.6 | 47.7 | 54.0 | 71.0 | 49.1 |

List of figures

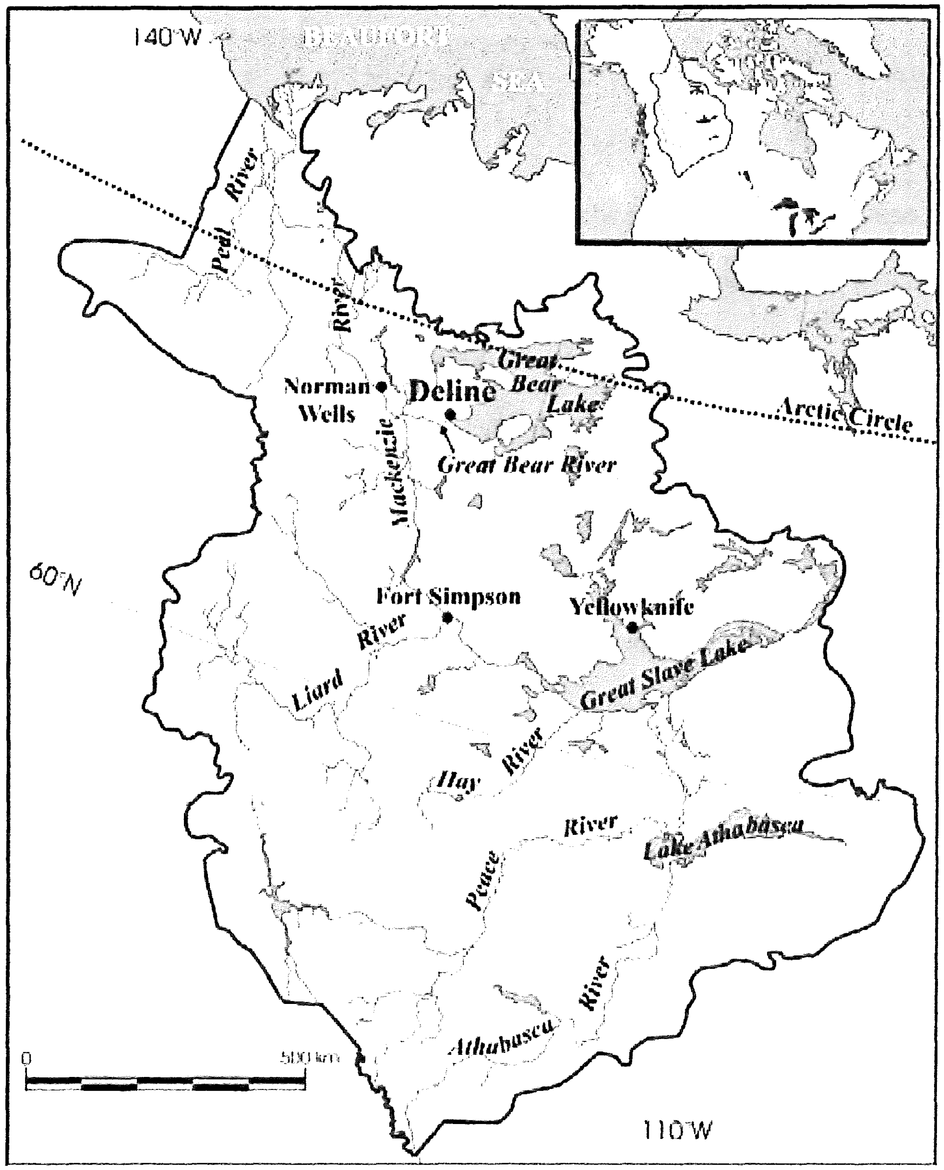


Figure 1: Location of Deline in the Mackenzie River Basin. Inset shows size and location of the Basin relative to the rest of Canada.

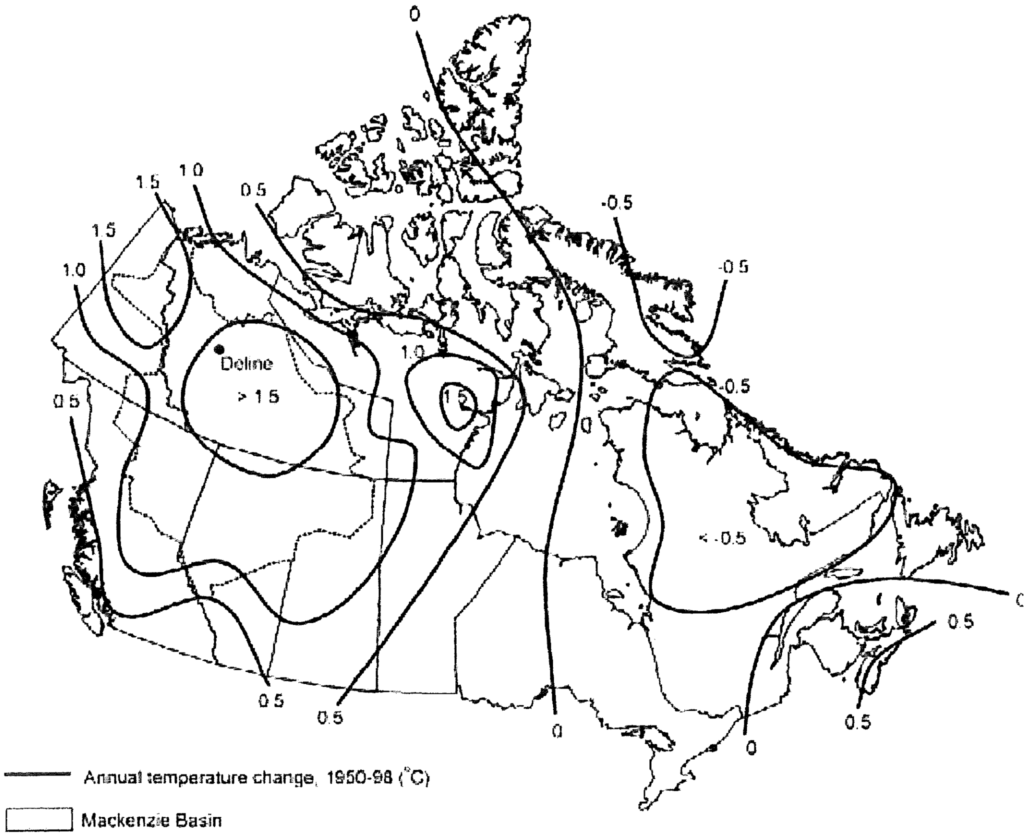


Figure 2: Isolines showing the temperature rise (in °C) in mean annual temperature between 1950 and 1988 (source: Environment Canada).

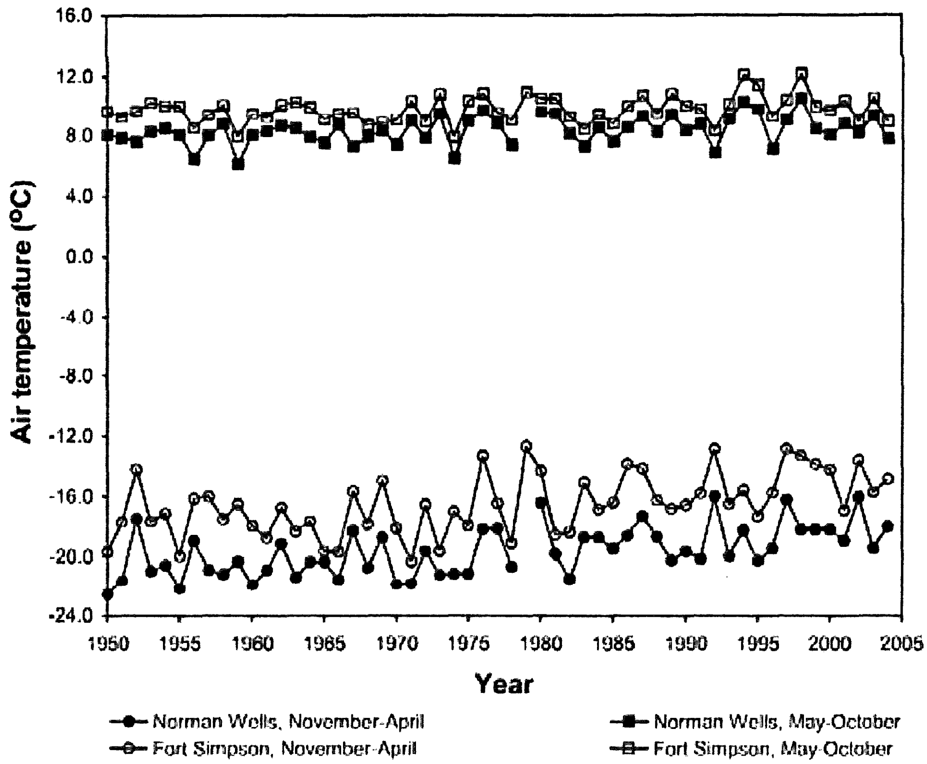


Figure 3: Winter (November to April) and summer (May to October) air temperature of Norman Wells and Fort Simpson, suggesting a significant warming trend between 1950 and 2004 during the winter but not the summer season (data source: Environment Canada).

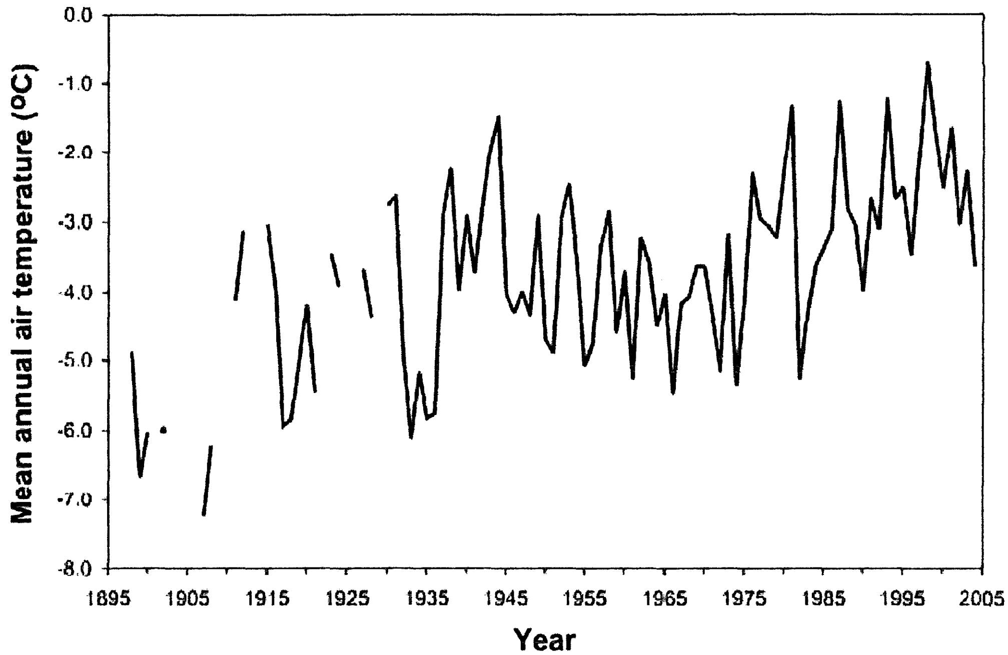


Figure 4: Variations in mean annual air temperature in the 20th Century, Fort Simpson. Gaps indicate missing data (data source: Environment Canada).

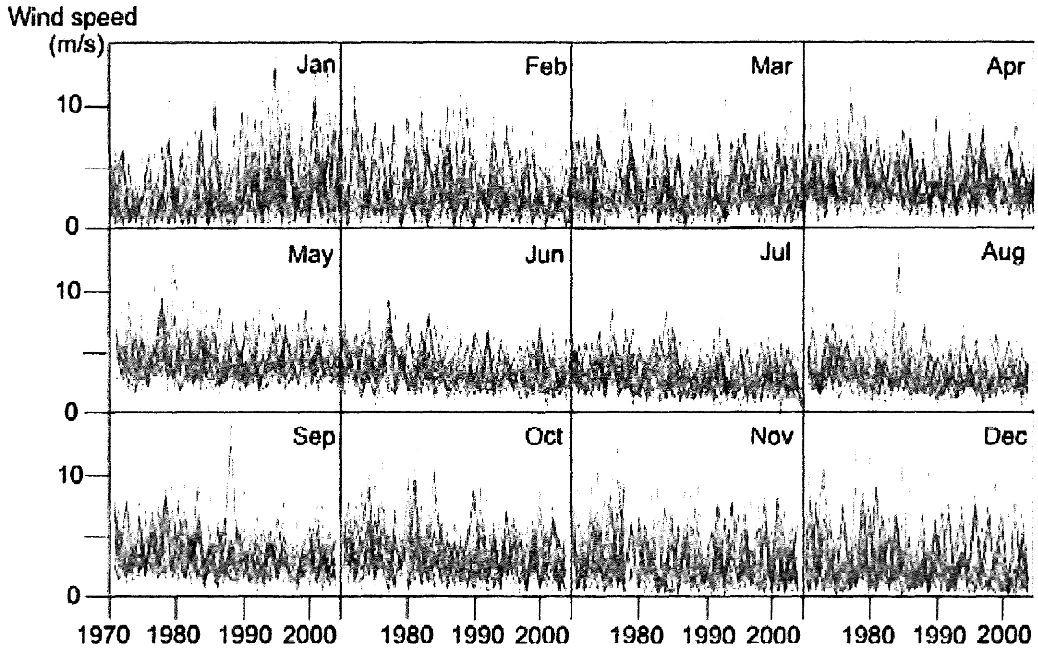


Figure 5: Daily wind speed at Norman Wells for different months. Each line shows the wind speed for a particular calendar day, over the period 1970-2004 (data source: Environment Canada).

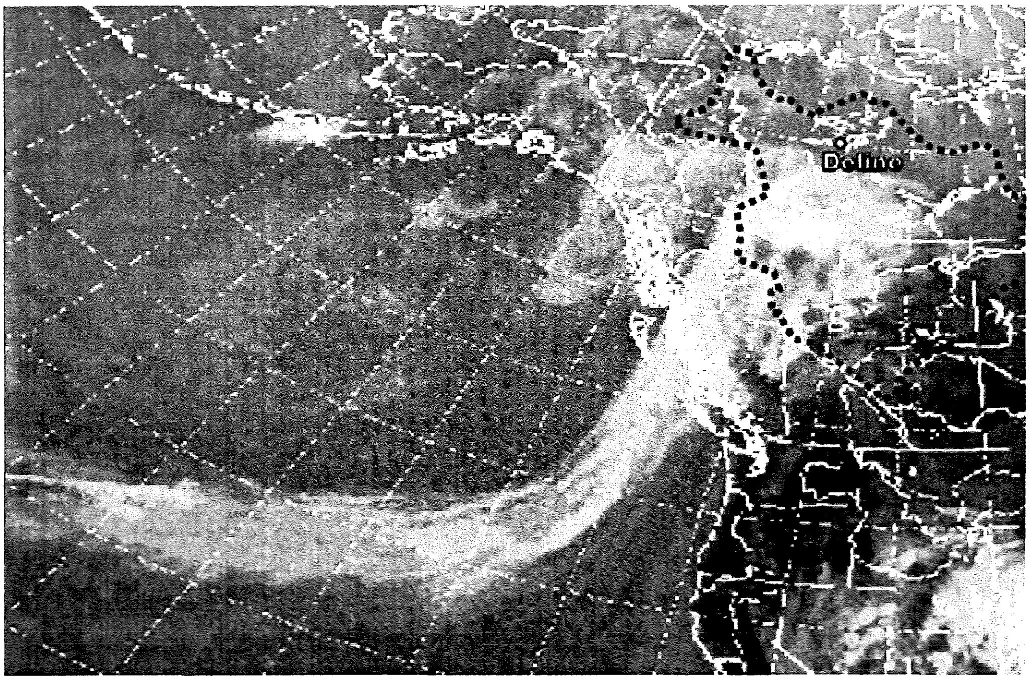


Figure 6: Satellite image (NOAHH – AVHRR) of the 'pineapple express' for 25 April 1999, showing a band of precipitation-bearing clouds that extends from near Hawaii (lower left corner) to western Canada. The Mackenzie River Basin is indicated by dotted line.

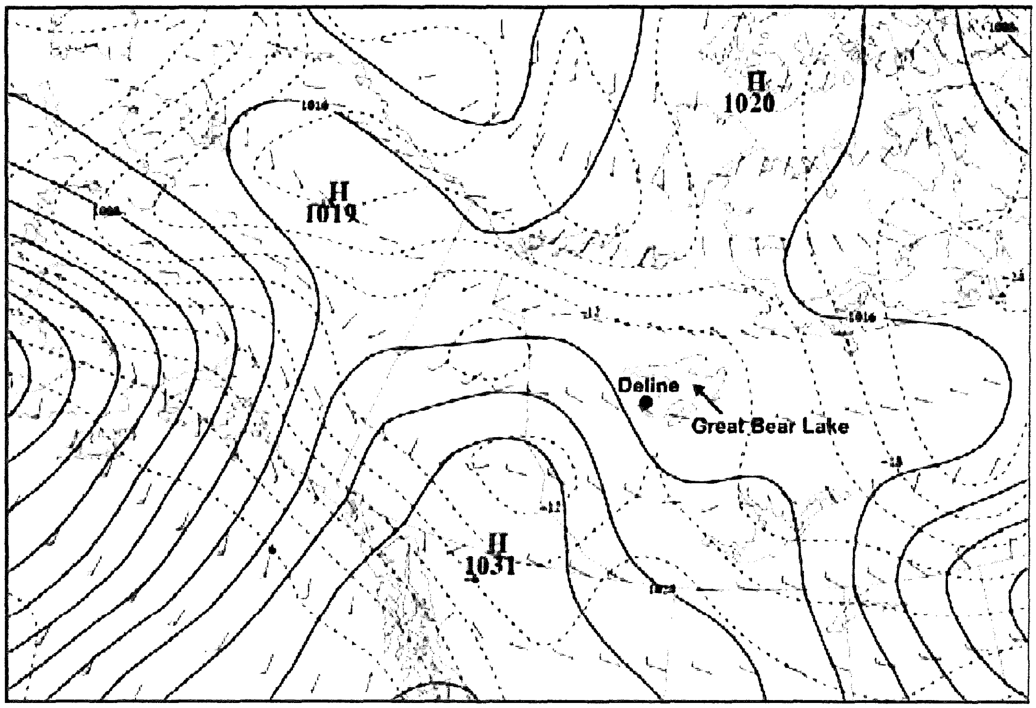


Figure 7: Wind condition on 10 November 2004 according to NCEP (National Centers for Environmental Prediction) Reanalysis, indicating low wind speed from westerly air flow across the Great Bear Lake region. Mean sea level pressure pattern is shown by isolines (in mbar).

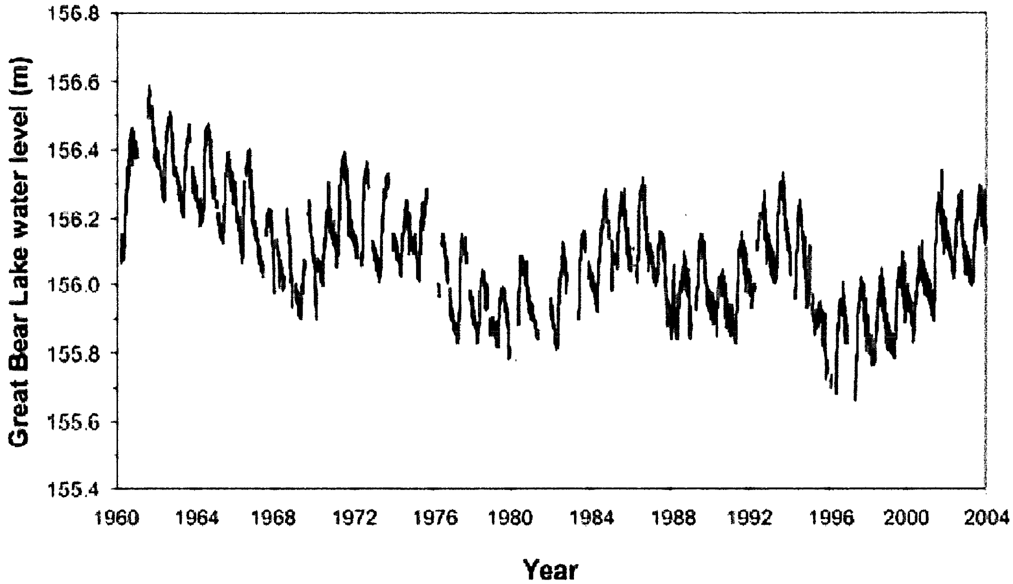


Figure 8: Mean daily water level of Great Bear Lake, 1960-2004 (data source: Water Survey of Canada).